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Shape Memory Alloy in Various Aviation Field

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Abstract

This paper depicts the way making use of the Shape Memory Alloy in aircraft hydraulic system and the feasibility accomplishing the concept of self-adapting deformable wing. The latest application of Shape Memory Alloy in aircraft engine variable section nozzle enlarged the Shape Memory Alloy serving territory. This paper describes the fundamental principle of Shape Memory Alloy and special material such as Shape Memory Alloy, sensor, actuator and electronic control cell together and bears load. The author summarizes the experience in hydraulic system using SMA and presents the difficulties and essentials in practice. Finally the author prospects SMA’s bright future in various fields of aircraft.

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Keywords: Shape Memory Alloy; Temperature; Tube joints; Self-adapting; engine; nozzle

1. Introduction

Since its date of birth, Shape Memory Alloy (SMA) has aroused continuous attention from material science circle and various industrial applications. This is mainly because of its two distinctive characteristics: shape memory effect (SME) and super elasticity (SE). Shape memory effect refers to the inside of alloy has formed phase transition under the influence of temperature, pressure, mechanical effect and other factors. While its outside manifests itself as relatively large plastic deformation and the alloy can be restored to its original state under the influence of temperature and other factors. Super elasticity means that the alloy is loaded at a certain temperature and undergoes certain deformation with the change of load. It can regain its original state after the load has been removed. The

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frontier research and application of SMA in aviation industry has attracted a lot of attention. Since its application in the hydraulic system tube of American F14 fighter in 1969, more than 1.5 million memory alloy tube joints have been used in various types of US aircraft. No case of leakage has been found because its reliability of connection and leak tightness has reached a very satisfactory degree. The US is the earliest country in carrying out research in the field of SMA and it is also the most active in popularizing and applying SMA in the field of aerospace. SMA is used in spacecraft antenna and aircraft hydraulic system by the US very early. Currently, TiNi SMA is widely used in aviation field, but it has various forms. According to the different needs of various systems, such as hydraulic pressure, pneumatic, environmental control, structure, TiNi SMA needs to take different material proportioning plans and lay particular emphasis on mechanical expansion and phase transition temperature. Major application direction has been carried out in sealing connection in hydraulic system, deformation of the engine nozzle, the research of wing deformation and the tight sealing of cabin door, etc. Among these, Andrew Peter Jardine has made important patents in the aspect of improving the aircraft door sealing [1].

Our country started late in the development of SMA. At present, more than 20 institutes are engaged in the development of SMA, and the most important ones of them are Institute of Metal of Chinese Academy of Sciences, Harbin Institute of Technology, Northwest Nonferrous Metals Research Institute, Beijing Nonferrous Metal Research Institute, Beijing University of Aeronautics and Astronautics and Shanghai Jiao Tong University, etc.. However, many years of market cultivation doesn't bring forth the maturity of large-scale industrialization of SMA. At the present time, there are about eight major companies engaged in the research and production of SMA, for instance, Xi'an Sai Te Metallic Material Co, Ltd., Beijing You Yan Yi Jin New Materials Co, Ltd., Jiang Yin Farr Sangit Co, Ltd [2].

After more than 20 years of development, now the domestic application of NiTi SMA is about dozens of tons every year. But it is worthwhile to note that the application of SMA in domestic aviation field is almost blank. According to the current situation, the domestic research of SMA in aviation field is in its beginning stage and there are no mature similar products available. But in recent years, with the advances of domestic technology and level of manufacturing crafts, the application of SMA tube in sealing connection of hydraulic system on Y12F airplane is a breakthrough and also the first large-scale use of SMA in domestic aviation field.

Based on the research and application of SMA in recent years, this paper aims at discussing its key problems, difficult points and development direction in the frontier of multidisciplinary fields and arouses people's attention to the research of this field.

2. Application of shape memory alloy in hydraulic system

2.1. The basic principle of low temperature memory alloy

The SMA applied in hydraulic system belongs to the type of TiNiFe alloy; this paper will introduce the basic principle of SMA by taking TiNiFe alloy as an example. The state of memory alloy will change under either high temperature or low temperature (Austenite vs. Martensite), and its metal ductility will increase at low temperatures.

At higher temperatures, the Austenite structure of SMA has similar pressure-tension curve as most metals.

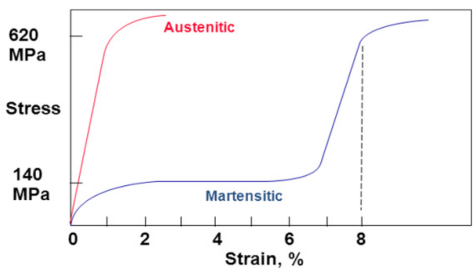

Fig. 1 pressure tension curve

While at lower temperatures, the pressure-tension curve of its Martensite structure presents elastic features when it is under stable pressure, as shown in figure 1.

As shown in Figure 2, the variation of the flexibility of memory alloy is about 8% at different temperatures and pressure. And this kind of change can be restored, but not simple [3].

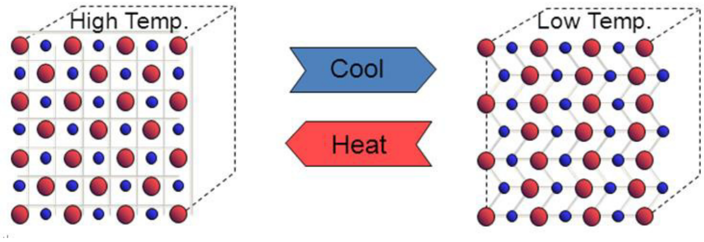

Fig. 2 changes in different temperature and pressure

2.2. How memory alloy works

In the production of memory alloy material into tube joints, through calculation, the joint is produced smaller than its outside diameter. Then the memory alloy is completely immersed in liquid nitrogen so as to change its structure into "Martensite". After that, the mechanical expansion of the inside diameter of memory alloy tube is realized through a conical steel core which is drilled through the inner wall of memory alloy. So the inside diameter is bigger than its outside diameter. Memory alloy tube is preserved in liquid nitrogen in order to maintain this expanded diameter (deformation Martensite structure).

In the assembling of aircraft tubes, memory alloy tube is taken out from liquid nitrogen and the tube ends are housed into the tube fittings. The memory alloy will return to "Austenite" structure freely at normal temperature. The inside diameter will contract to the original size, namely, the inside diameter is slightly smaller than the outside diameter. Thus, the tube is connected without using special tools, special operation and without leakage. Part of the section structure is shown in figure 3.

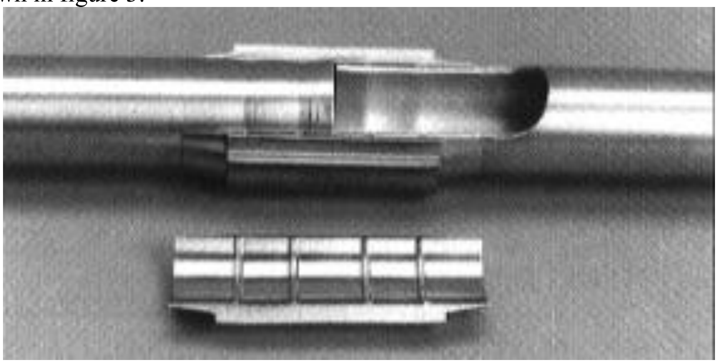

Fig. 3 memory alloy tube connection profile

At present, the application of SMA in the hydraulic system of Y12F is a breakthrough in aircraft installing in our country. It has been tested by 3 planes and 400 hours of flight, that is, no case of leakage will be found if the tube is correctly connected.

The advantages of memory alloy connection are: (1) memory alloy tube fittings is lighter over 60% than traditional tube fittings and its compression performance can reach 5000Psi, special memory alloy tube can reach 8000Psi, (2) memory alloy tube joint has many advantages: smaller volume, smaller space occupation, compact structure, large amount of interference , with high coordination strength and good sealing performance, (3) the cost of memory alloy tube connection is 40% cheaper than traditional tube assembling, (4) the anti-corrosion properties of TiNi based shape memory alloys are particularly good, it has strong adaptability and is suitable for the connection among dissimilar materials which cannot be welded, (5) it is convenient to install and operate, and it only takes 15-30 seconds to complete the joint and sealing of tubes.

2.3. The difficulties of memory alloy connection

Shape reconstruction depending on the reverse phase transition between Martensitic and Austenite can make tube joints realize its connection of tubeline. The Ms and As of TiNiFe alloy are -150, -88 ℃ respectively, phase transition hysteresis is 62 ℃. Thus after the expansion of the diameter, TiNiFe SMA tube joint must be stored, transported and assembled at liquid nitrogen temperature, which brings great inconvenience to the use of tube joint. Figure 4 is the diameter change of memory alloy tube in the heating and cooling process.

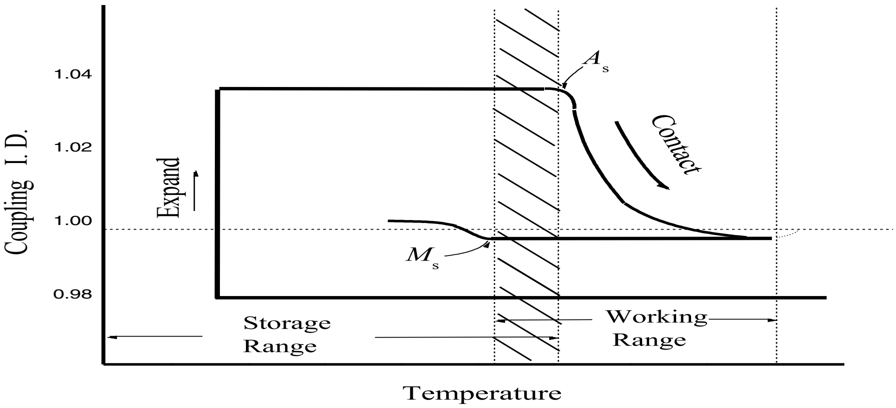

Fig. 4 Schematic diagram of tube diameter change

When the temperature is rising higher than the As, the diameter of tube joint began to shrink. On the other hand, when the temperature is lower than Ms, the diameter of tube joint began to swell. Considering its application, the temperature (Ms) should be as low as possible when parent phase is transformed to Martensitic. Keeping away from Ms can avoid the connection relaxation caused by phase transition of Martensitic when the working temperature is close to Ms. From the point of storage, transportation and assembling, the temperature should be as high as possible during the reverse transition process from Martensitic to parent phase. This needs to change a wide hysteresis. Therefore, Researching shape memory alloy can be stored at room temperature, transport and assembly with memory alloy wide hysteresis becomes a research direction of shape memory alloy. In 1986, American Raychem Company developed the TiNiNb shape memory alloy. The alloy improves the stability of martensite, increases transformation hysteresis width obviously with deformation appropriate in low temperature condition. Tube joints or fasteners made of this alloy can be stored or transports, at room temperature, bring great convenience for engineering application.

At present in China we have some technical difficulties: (1) the material: NiTiNb alloy composition is not complicated, but production requirements are very high. In order to obtain satisfactory material and tube joints, the key technology is to solve the material preparation. (2) the tube joint design and manufacturing: shape memory alloy tube and connecting tube is a kind of interference fit, the amount of interference about tube wall thickness and connecting tube is both the key joint design, In addition, compared with the TiNiFe the deformation of TiNiNb memory alloy tube joints under low temperature can reach 10%, it is difficult to design and manufacture the tube joint.

3. Application of shape memory alloy in the structure

3.1. Self-adapting wing structure of shape memory alloy

Self-adapting structure refers to the base material, sensing element, driving element and electronic control system are integrated into a whole, the system can not only loads capacity, transmits motion, but also has the ability of detection, motor and change the structure characteristics. And according to the external changing environment and their own situation, they can adapt based on self diagnosis of the structure adjustment. If the aircraft wings have self-adapting deformation ability, they can improve the performance of the system to a great extent, especially in improving the radius of gyration, increasing endurance, increasing the load and improving the obvious advantages of maximum speed [4].

3.2. Engine nozzle of shape memory alloy

American research and application of shape memory alloy in engine nozzle field began with an intelligent aerospace and marine propulsion system demonstration program (SAMPSON program). The plan is supported by DARPA, and led by NASA.NASA proposed a project to obtain flying benefit according to the flight condition to make the inlet geometry optimization and improvement, to evaluate and demonstrate the technology about intelligent material structure deformation ability to the plan. The study of memory alloy variable section engine nozzle officially boarded the stage of history from that.

America has made remarkable achievements indeed in the memory alloy structural subject through continuous research and Forward-looking experiment, and quickly converts them into applicable results. In 2010, the Boeing company disclosed an invention in China. This is a plane structure according to the flight operation dynamically which can change the shape of the shape memory alloy driving. The deformable structure driven by shape memory alloy actuator is coupled to the deformable structure panel. Deformable structure can get complicated shape changes through changing activation of memory alloy actuator shape. Memory alloy actuator according to operating conditions changes in temperature change through the active or passive temperature driven. The structure of the invention can be used for deformation nozzle, such as variable area fan nozzle in jet engines to reduce the noise of the engine during takeoff, but not make the combustion of the fuel degradation during the cruise.

China also carried out research in related fields, such as structure design of stealth fighter need to drive the folding wing with shape memory alloy; recently Chengdu aircraft group also introduced the manufacturing process of memory alloy technology [5]. But in general what we researched about memory alloy structure is in a backward position, the transformation and application of scientific research results is slow.

4. Conclusion

In the aviation field, the application of SMA undergoes constant breakthrough in several directions from the application of independent properties of materials to its combination with electronic and hydraulic technology. Its application in the subjects of aviation field is expanding. SMA materials could integrate sensing, control and drive into one body because of its unique memory effect and high energy density. Through specific servo control mechanism, SMA materials can realize the conversion of electro-mechanical energy. It can be controlled flexibly, actuated compliantly, and produced no vibration and noise. Thus the micromation and integration of structure can be realized. If the sensors and actuators made of SMA and piezoelectric polymer can be placed in advanced composite materials, then the active control and material damage healing of material properties, structure, vibration and noise absorption can be realized. These techniques are not discussed in detail in this paper, but they will have a brilliant future in many subjects in aircraft field. Although SMA has obtained many application achievements in aviation field, it still faces many difficulties in its development. For example, the development of driving device of SMA structure, particularly the increase of its speed of response and frequency, is of utmost importance in its subsequent development. Another aspect is to increase the self-adapting ability of SMA materials at high and low temperatures, so it could be applied more widely.

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